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TITLE: Theoretical and Analytical Research on Space Plasma Physics

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SUMMARY OF WORK ACCOMPLISHED UNDER THIS GRANT

1960-1965

During this period the main effort was directed towards a study of the physics controlling the F region of the ionosphere. When this work started it was widely assumed that the recombination coefficient at 300 km was approximately constant and the "Bradbury hypothesis", that the F1 and F2 layers had a common origin, was unproven. By studying nighttime decay of the region it was shown by Nisbet and Quinn [1963], Quinn and Nisbet [1965] and Nisbet and McCrory [1966] that the recombination rate at 300km varied by nearly two orders of magnitude with temperature. When these values were related to Nicolet's thermospheric models it became apparent that the variations were due mainly to changes in the densities of N_2 and O_2 which controlled the atom ion recombination rate for the O^+ ions. Values of the dissociative recombination coefficient were also obtained which differed by an order of magnitude from accepted values at that time but which are close to current values. New analytic models of the F region electron density under daytime equilibrium conditions [Nisbet, 1963] were developed which allowed the daytime production to be related to the nightime recombination. This work paved the way for theoretically based ionospheric models.

1963-1967

A major focus of attention in this period was the study of the factors controlling the electron, ion and neutral temperatures in the E and F regions of the ionosphere. A method was developed for solving the energy conservation equations for electron and ions to obtain the neutral temperatures and densities [Nisbet 1967]. This considerably expanded the usefulness of incoherent scatter observations for aeronomic measurements by allowing not just the electron and ion temperatures to be deduced but also the neutral temperatures and densities. This was to lead to major improvements in thermospheric models. This work showed that the thermospheric models in use at that time were very seriously in error. These models were based on satellite orbital decay rates with the assumption that the atmosphere was in diffusive equilibrium above constant boundary conditions at 120 km. It had been erroneously assumed densities were uniquely related to thermospheric temperatures. Incoherent scatter measurements showed that the maximum in the total density at 14 hr local time and at the equator deduced from satellite orbital decay were not reflected in corresponding maxima in the thermospheric temperatures which occurred in the summer auroral zone.

1965-1972

Observations by Carlson and Nisbet [1966] at Arecibo showed that the electron temperature in the upper F region increased at the time of conjugate sunrise in the ionosphere. This was shown to be due to photoelectrons emitted from the conjugate hemisphere. Photoelectron transport had just been predicted by Hanson. The modified diffusion technique was developed to study transport and escape of electrons in the ionosphere [Nisbet 1968]. This work was continued by Swartz and Nisbet [1972]. Cicerone et al. [1973] compared the results of this technique with those of the two stream method of Nagy and Banks [1970], Banks and Nagy [1970], and the Monte Carlo technique of Cicerone and Bowhill [1970, 1971] and showed excellent agreement between all three methods despite orders of magnitude differences with other early calculation techniques.

1968-1975

During this period the first theoretically based model of the E and F regions of the ionosphere was developed [Nisbet 1971]. The Penn State MKI Ionospheric model was the first large global ionospheric model that could be used by unskilled personnel to make ionospheric predictions. The model has been used for an enormous range of applications including propagation studies, satellite ambient condition studies, experiment planning, and system performance simulation. It is still one of the most accurate predictive models available. This model was coupled to a ray tracing program for propagation predictions [Lee and Nisbet 1975].

1971-1973

The effect of energetic atomic oxygen atoms on neutral density models was examined [Rohrbaugh and Nisbet, 1973]. It was shown that above 600 km these non-thermal atoms dominate the atomic oxygen distribution. This was one of the earliest studies of the distribution of an energetic neutral species produced by charge exchange with an energetic ion. Such studies have now become of major importance in the magnetosphere both from their intrinsic interest as well as for their usefulness as a diagnostic tool since neutral particles can be imaged and are not deflected by magnetic fields. This work was later extended to a study of the effect of energetically produced O_2^+ on ion temperatures in the Martian thermosphere [Rohrbaugh et al. 1979].

1973-1983

Studies of the neutral atmosphere and the ionosphere show that they have very large day-to-day variations that are not correlated in any simple way with the incident EUV solar flux [Nisbet et al. 1981; Nisbet and Stehle 1981]. These were shown to be due mainly to high latitude heating and neutral winds driven by the electric fields in the auroral electrojet region [Nisbet and Glenar, 1977; Glenar, Bleular, and Nisbet 1978].

1980-1990

Two major problems caused us to start a program of investigation of the electrification of thunderstorms. The first was the suggestion that solar wind sector crossings were related to thunderstorm incidence in the great plains. We had a model of the ionosphere with the electric fields and particle inputs that could respond realistically to solar wind inputs and so all that seemed to be required was to couple this to models of thunderclouds to be able to check out the interactions. We discovered, however, that there were no dynamic electric models of a thundercloud cell. The second problem arose out of the danger of lightning damage to spacecraft during launch. There were no electrodynamic models that would allow the surface electric fields measured by the KSFC network to be related to the current systems and electric fields in the clouds above.

The primary object of this study was to develop electrodynamic models of thunderclouds which treated the evolution of the generator and the lightning, and were coupled to the earth-ionosphere current system. These models were to be used to firstly examine the relationships between the measurable current systems and the physical development of the cloud electrification system, to investigate the relation of the dynamic current system in the thundercloud and the currents to maintain the fair weather field, and finally to develop and use models capable of analyzing the development of a real thundercloud.

A simple model was developed which modeled the thundercloud dynamic electric fields [Nisbet 1983]. This was later used to study the way currents in a thunderstorm cell could be measured from current measurements to the ground [Nisbet 1985a] and the relation of the currents to the ionosphere to the electrical development of the thunderstorm cells [Nisbet 1985b].

To simulate actual storm cell development required a model with matrices that were two orders of magnitude larger and took three orders of magnitude less time to solve [Hager et al. 1989a, b]. These were used to analyze the complete development of two cells of a Florida thunderstorm [Nisbet et al. 1990a, b]. The charge moment separated was calculated and related to the charge moments recombining in intra and cloud-to-ground lightning throughout the life each of the cells. The morphology of the charge moment development showed conclusively that the electrification was caused by the separation of two components from an originally neutral ensemble in the region of 7.5 km. The charge generation rates were related to the flash rates. The energy balance of the cells was investigated. The size of the heavy component of the charge particles was estimated. The statistical distributions for the charge moments of cloud-to-ground and intracloud lightning were measured. A comprehensive study of the transport properties of the ice and water particles in thunderstorms was made [Nisbet, 1979].

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